

An Ancient Greek Computer

In 1901 divers working off the isle of Antikythera found the remains of a clocklike mechanism 2,000 years old. The mechanism now appears to have been a device for calculating the motions of stars and planets

by Derek J. de Solla Price

Among the treasures of the Greek National Archaeological Museum in Athens are the remains of the most complex scientific object that has been preserved from antiquity. Corroded and crumbling from 2,000 years under the sea, its dials, gear wheels and inscribed plates present the historian with a tantalizing problem. Because of them we may have to revise many of our estimates of Greek science. By studying them we may find vital clues to the true origins of that high scientific technology which hitherto has seemed peculiar to our modern civilization, setting it apart from all cultures of the past.

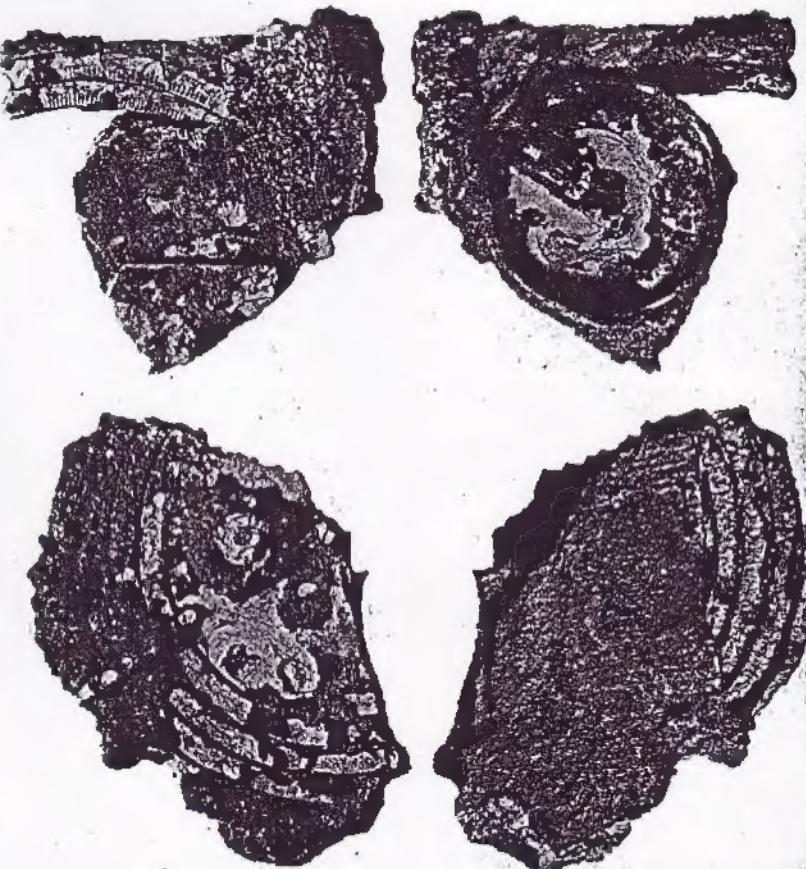
From the evidence of the fragments one can get a good idea of the appearance of the original object [see illustration on page 62]. Consisting of a box with dials on the outside and a very complex assembly of gear wheels mounted within, it must have resembled a well-made 18th-century clock. Doors hinged to the box served to protect the dials, and on all available surfaces of box, doors and dials there were long Greek inscriptions describing the operation and construction of the instrument. At least 20 gear wheels of the mechanism have been preserved, including a very sophisticated assembly of gears that were mounted eccentrically on a turntable and probably functioned as a sort of epicyclic or differential gear-system.

Nothing like this instrument is preserved elsewhere. Nothing comparable to it is known from any ancient scientific text or literary allusion. On the contrary, from all that we know of science and technology in the Hellenistic Age we should have felt that such a device could not exist. Some historians have suggested that the Greeks were not interested in experiment because of a contempt—perhaps induced by the existence

of the institution of slavery—for manual labor. On the other hand it has long been recognized that in abstract mathematics and in mathematical astronomy they were no beginners but rather "fellows of another college" who reached great heights of sophistication. Many of the Greek scientific devices known to us from written descriptions show much mathematical ingenuity, but in all cases

the purely mechanical part of the design seems relatively crude. Gearing was clearly known to the Greeks, but it was used only in relatively simple applications. They employed pairs of gears to change angular speed or mechanical advantage, or to apply power through a right angle, as in the water-driven mill.

Even the most complex mechanical devices described by the ancient writers



THREE PRINCIPAL FRAGMENTS of the Antikythera mechanism are shown from both sides. One pair of views is at top on the left-hand page; the second pair, at bottom on the

Hero of Alexandria and Vitruvius contained only simple gearing. For example, the taximeter used by the Greeks to measure the distance traveled by the wheels of a carriage employed only pairs of gears (or gears and worms) to achieve the necessary ratio of movement. It could be argued that if the Greeks knew the principle of gearing, they should have had no difficulty in constructing mechanisms as complex as epicyclic gears. We now know from the fragments in the National Museum that the Greeks did make such mechanisms, but the knowledge is so unexpected that some scholars at first thought that the fragments must belong to some more modern device.

Can we in fact be sure that the device is ancient? If we can, what was its purpose? What can it tell us of the ancient world and of the evolution of modern science?

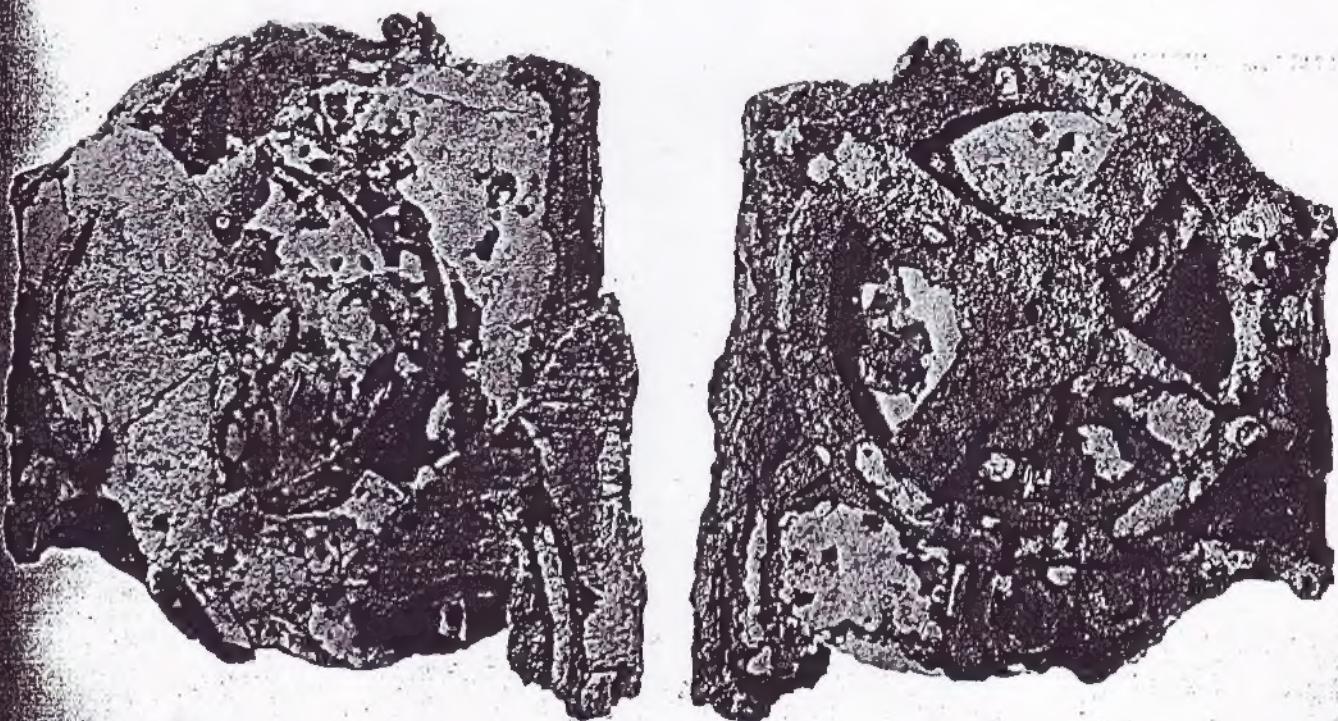
To authenticate the dating of the fragments we must tell the story of their discovery, which involves the first (though inadvertent) adventure in underwater archaeology. Just before Easter in 1900 a party of Dodecanese sponge-

divers were driven by storm to anchor near the tiny southern Greek island of Antikythera (the accent is on the "kyth," pronounced to rhyme with *pith*). There, at a depth of some 200 feet, they found the wreck of an ancient ship. With the help of Greek archaeologists the wreck was explored; several fine bronze and marble statues and other objects were recovered. The finds created great excitement, but the difficulties of diving without heavy equipment were immense, and in September, 1901, the "dig" was abandoned. Eight months later Valerios Stais, an archaeologist at the National Museum, was examining some calcified lumps of corroded bronze that had been set aside as possible pieces of broken statuary. Suddenly he recognized among them the fragments of a mechanism.

It is now accepted that the wreck occurred during the first century B.C. Gladys Weinberg of Athens has been kind enough to report to me the results of several recent archaeological examinations of the amphorae, pottery and minor objects from the ship. It appears from her report that one might reason-

ably date the wreck more closely as 65 B.C. ± 15 years. Furthermore, since the identifiable objects come from Rhodes and Cos, it seems that the ship may have been voyaging from these islands to Rome, perhaps without calling at the Greek mainland.

The fragment that first caught the eye of Stais was one of the corroded, inscribed plates that is an integral part of the Antikythera mechanism, as the device later came to be called. Stais saw immediately that the inscription was ancient. In the opinion of the epigrapher Benjamin Dean Meritt, the forms of the letters are those of the first century B.C.; they could hardly be older than 100 B.C. nor younger than the time of Christ. The dating is supported by the content of the inscriptions. The words used and their astronomical sense are all of this period. For example, the most extensive and complete piece of inscription is part of a parapegma (astronomical calendar) similar to that written by one Geminus, who is thought to have lived in Rhodes about 77 B.C. We may thus be reasonably sure that the mechanism did not find its way into the wreck at some later



left-hand page; the third pair, on the right-hand page. How the fragments were used to reconstruct the appearance of the original mech-

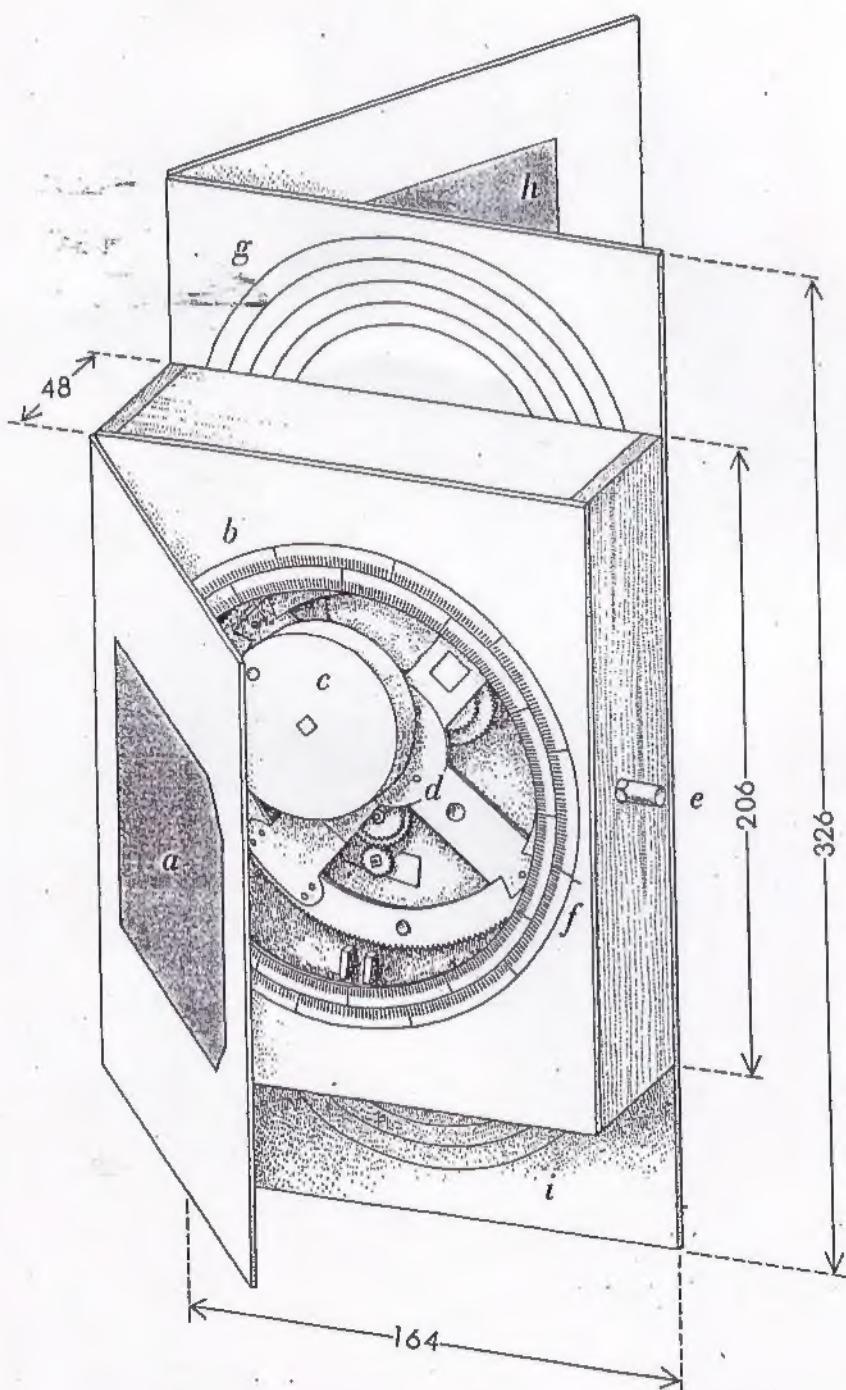
anism is shown on the next two pages. The fragments are presently located in the Greek National Archaeological Museum in Athens.

period. Furthermore, it cannot have been very old when it was taken aboard the ship as booty or merchandise.

As soon as the fragments had been discovered they were examined by every available archaeologist; so began the long and difficult process of identifying the mechanism and determining its function. Some things were clear from the beginning. The unique importance of

the object was obvious, and the gearing was impressively complex. From the inscriptions and the dials the mechanism was correctly identified as an astronomical device. The first conjecture was that it was some kind of navigating instrument—perhaps an astrolabe (a sort of circular star-finder map also used for simple observations). Some thought that it might be a small planetarium of the

kind that Archimedes is said to have made. Unfortunately the fragments were covered by a thick curtain of calcified material and corrosion products, and these concealed so much detail that no one could be sure of his conjectures or reconstructions. There was nothing to do but wait for the slow and delicate work of the Museum technicians in cleaning away this curtain. Meantime, as the



MECHANISM IS PARTLY RECONSTRUCTED at left. Exploded diagram at right shows how the fragments (color) are related to

the plates of the mechanism. Some fragments include parts of more than one plate. The labeled parts in the reconstruction are:

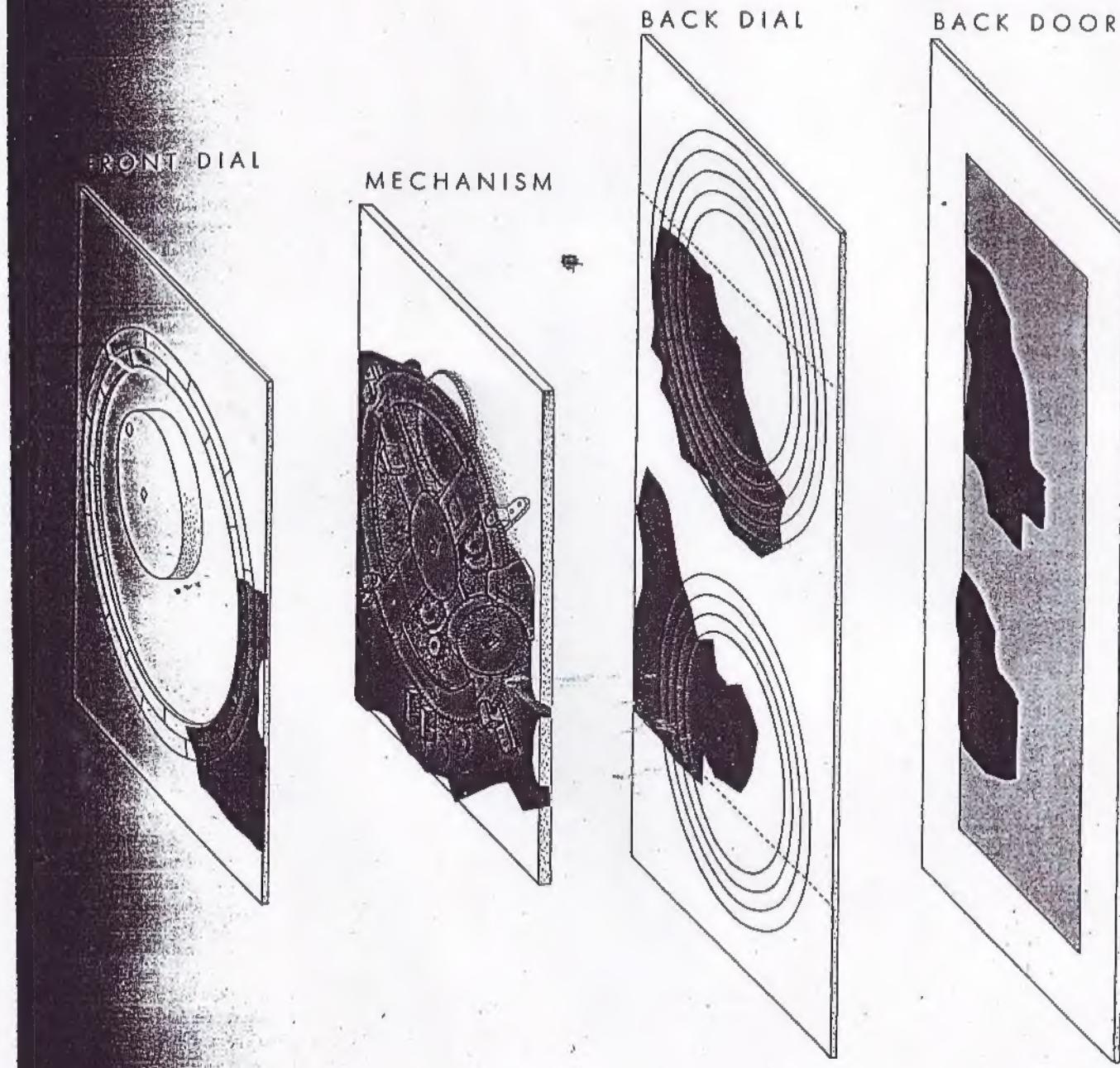
work proceeded, several scholars published accounts of all that was visible, and through their labors a general picture of the mechanism began to emerge.

On the basis of new photographs made for me by the Museum in 1955 I realized that the work of cleaning had reached a point where it might at last

be possible to take the work of identification to a new level. Last summer, with the assistance of a grant from the American Philosophical Society, I was able to visit Athens and make a minute examination of the fragments. By good fortune George Stamires, a Greek epigrapher, was there at the same time; he was able to give me invaluable help by deciphering and transcribing much more of the

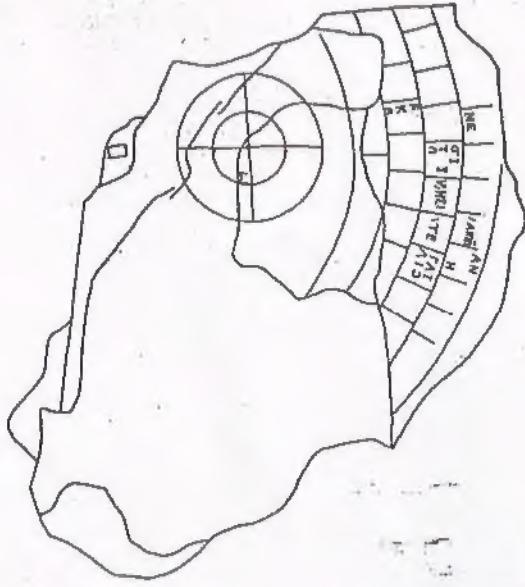
inscriptions than had been read before.

We are now in the position of being able to "join" the fragments and to see how they fitted together in the original machine and when they were brought up from the sea [see illustrations on these two pages]. The success of this work has been most significant, for previously it had been supposed that the various dials and plates had been badly squashed to-

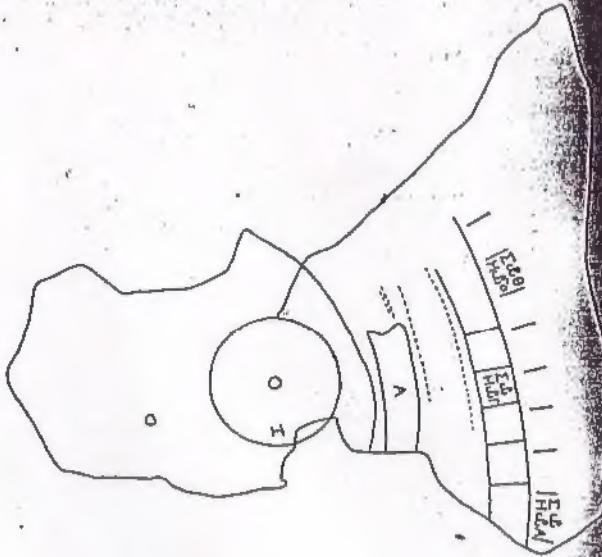


Front inscription (a), front dial (b), eccentric drum (c), front of mechanism (d), input shaft (e), fiducial mark (f), four slip rings

of upper back dial (g), back-door inscription (h), three slip rings of lower back dial (i). The dimensions are given in millimeters.



SEGMENTS OF THREE DIALS of the mechanism are visible in the fragments. At left is a simplified drawing of one fragment showing a segment of the upper back dial. At upper right in this



drawing may be seen the four slip rings of the dial; within the rings is a small subsidiary dial. Second from left is a segment of the lower back dial. At right in this drawing is a fixed scale; within it

is

gether and distorted. It now appears that most of the pieces are very nearly in their original places, and that we have a much larger fraction of the complete device than had been thought. This work also provides a clue to the puzzle of why the fragments lay unrecognized until Staës saw them. When they were found, the fragments were probably held together in their original positions by the remains of the wooden frame of the case. In the Museum the waterlogged wood dried and shriveled. The fragments then fell apart, revealing the interior of the mechanism, with its gears and inscribed plates.

As a result of the new examinations we shall in due course be able to publish a technical account of the fragments and of the construction of the instrument. In the meantime we can tentatively summarize some of these results and show how they help to answer the question: What is it?

There are four ways of getting at the answer. First, if we knew the details of the mechanism, we should know what it did. Second, if we could read the dials, we could tell what they showed. Third, if we could understand the inscriptions, they might tell us about the mechanism. Fourth, if we knew of any similar mechanism, analogies might be helpful. All these approaches must be used, for none of them is complete.

The geared wheels within the mechanism were mounted on a bronze plate [third from right on preceding page]. On one side of the plate we can trace all the

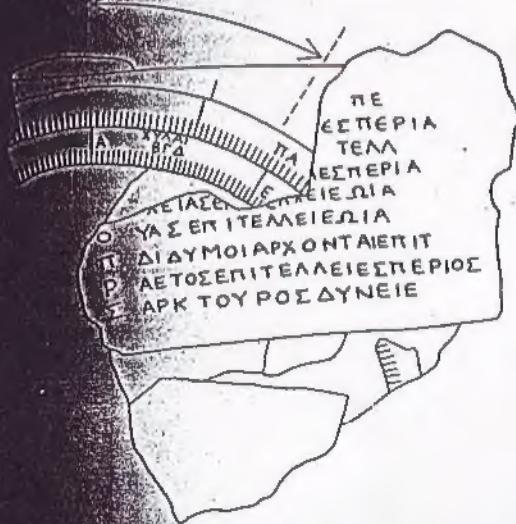
gear wheels of the assembly and can determine, at least approximately, how many teeth each had and how they meshed together. On the other side we can do nearly as well, but we still lack vital links that would provide a complete picture of the gearing. The general pattern of the mechanism is nonetheless quite clear. An input was provided by an axle that came through the side of the casing and turned a crown-gear wheel. This moved a big, four-spoked driving-wheel that was connected with two trains of gears that respectively led up and down the plate and were connected by axles to gears on the other side of the plate. On that side the gear trains continued, leading through an epicyclic turntable and coming eventually to a set of shafts that turned the dial pointers. When the input axle was turned, the pointers all moved at various speeds around their dials.

Certain structural features of the mechanism deserve special attention. All the metal parts of the machine seem to have been cut from a single sheet of low-tin bronze about two millimeters thick; no parts were cast or made of another metal. There are indications that the maker may have used a sheet made much earlier—uniform metal plate of good quality was probably rare and expensive. All the gear wheels have been made with teeth of just the same angle (60 degrees) and size, so that any wheel could mesh with any other. There are signs that the machine was repaired at least twice; a spoke of the driving wheel

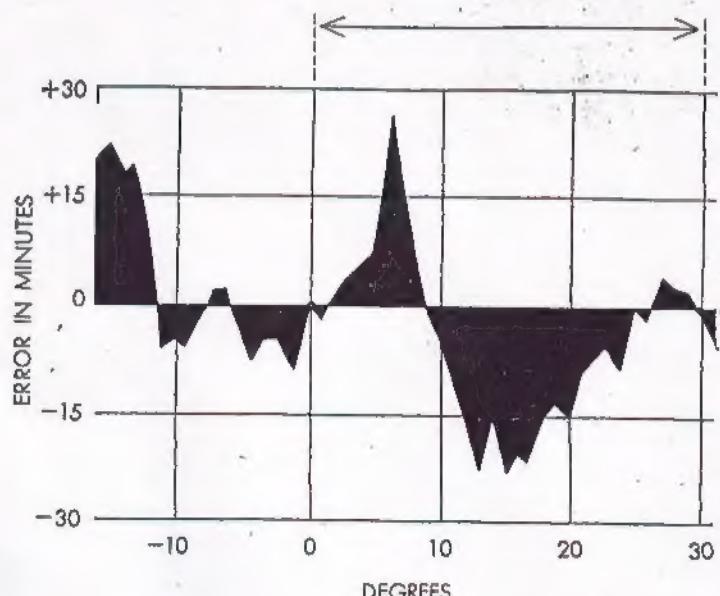
has been mended, and a broken tooth in a small wheel has been replaced. This indicates that the machine actually worked.

The casing was provided with three dials, one at the front and two at the back. The fragments of all of them are still covered with pieces of the doors of the casing and with other debris. Very little can be read on the dials, but there hope that they can be cleaned sufficiently to provide information that might be decisive. The front dial is just clean enough to say exactly what it did. It has two scales, one of which is fixed and displays the names of the signs of the zodiac; the other is on a movable slip ring and shows the months of the year. Both scales are carefully marked off in degrees. The front dial fitted exactly over the main driving wheel, which seems to have turned the pointers by means of an eccentric drum assembly. Clearly this dial showed the annual motion of the sun in the zodiac. By means of key letters inscribed on the zodiac scale, corresponding to other letters on the parapegma calendar plate, it also showed the main risings and settings of bright stars and constellations throughout the year.

The back dials are more complex and less legible. The lower one had three slip rings; the upper, four. Each had a little subsidiary dial resembling the "seconds" dial of a watch. Each of the large dials is inscribed with lines about every six degrees, and between the lines there are letters and numbers. On the



were three slip rings and within them a subsidiary dial. Third from left is a segment of the front dial. The upper scale in this drawing pertains to the months; the lower scale, to the zodiac. The in-



scribed area is a parapegma plate. The graph at far right shows the errors (in minutes of arc) of the graduations in the zodiac scale. The arrow above the scale is related to the arrow above the chart.

lower dial the letters and numbers seem to record "moon, so many hours; sun, so many hours"; we therefore suggest that this scale indicates the main lunar phenomena of phases and times of rising and setting. On the upper dial the inscriptions are much more crowded and might well present information on the risings and settings, stations and retrogradations of the planets known to the Greeks (Mercury, Venus, Mars, Jupiter and Saturn).

Some of the technical details of the dials are especially interesting. The front dial provides the only known extensive specimen from antiquity of a scientifically graduated instrument. When we measure the accuracy of the graduations under the microscope, we find that their average error over the visible 45 degrees is about a quarter of a degree. The way in which the error varies suggests that the arc was first geometrically divided and then subdivided by eye only. Even more important, this dial may give a means of dating the instrument astronomically. The slip ring is necessary because the old Egyptian calendar, having no leap years, fell into error by 1/4 day every year; the month scale thus had to be adjusted by this amount. As they are preserved the two scales of the dial are out of phase by 13½ degrees. Standard tables show that this amount could only occur in the year 80 B.C. and (because we do not know the month) at all years just 120 years (i.e., 30 days divided by 1/4 day per year) before or after that date. Alternative dates are archaeologi-

cally unlikely: 200 B.C. is too early; 40 A.D. is too late. Hence, if the slip ring has not moved from its last position, it was set in 80 B.C. Furthermore, if we are right in supposing that a fiducial mark near the month scale was put there originally to provide a means of setting that scale in case of accidental movement, we can tell more. This mark is exactly 1/2 degree away from the present position of the scale, and this implies that the mark was made two years before the setting. Thus, although the evidence is by no means conclusive, we are led to suggest that the instrument was made about 82 B.C., used for two years (just long enough for the repairs to have been needed) and then taken onto the ship within the next 80 years.

The fragments show that the original instrument carried at least four large areas of inscription: outside the front door, inside the back door, on the plate between the two back dials and on the parapegma plates near the front dial. As I have noted, there are also inscriptions around all the dials, and furthermore each part and hole would seem to have had identifying letters so that the pieces could be put together in the correct order and position. The main inscriptions are in a sorry state and only short snatches of them can be read. To provide an idea of their condition it need only be said that in some cases a plate has completely disappeared, leaving behind an impression of its letters, standing up in a mirror image, in relief on the soft cor-

rosion products on the plate below. It is remarkable that such inscriptions can be read at all.

But even from the evidence of a few complete words one can get an idea of the subject matter. The sun is mentioned several times, and the planet Venus once; terms are used that refer to the stations and retrogradations of planets; the ecliptic is named. Pointers, apparently those of the dials, are mentioned. A line of one inscription significantly records "76 years, 19 years." This refers to the well-known Calippic cycle of 76 years, which is four times the Metonic cycle of 19 years, or 235 synodic (lunar) months. The next line includes the number "223," which refers to the eclipse cycle of 223 lunar months.

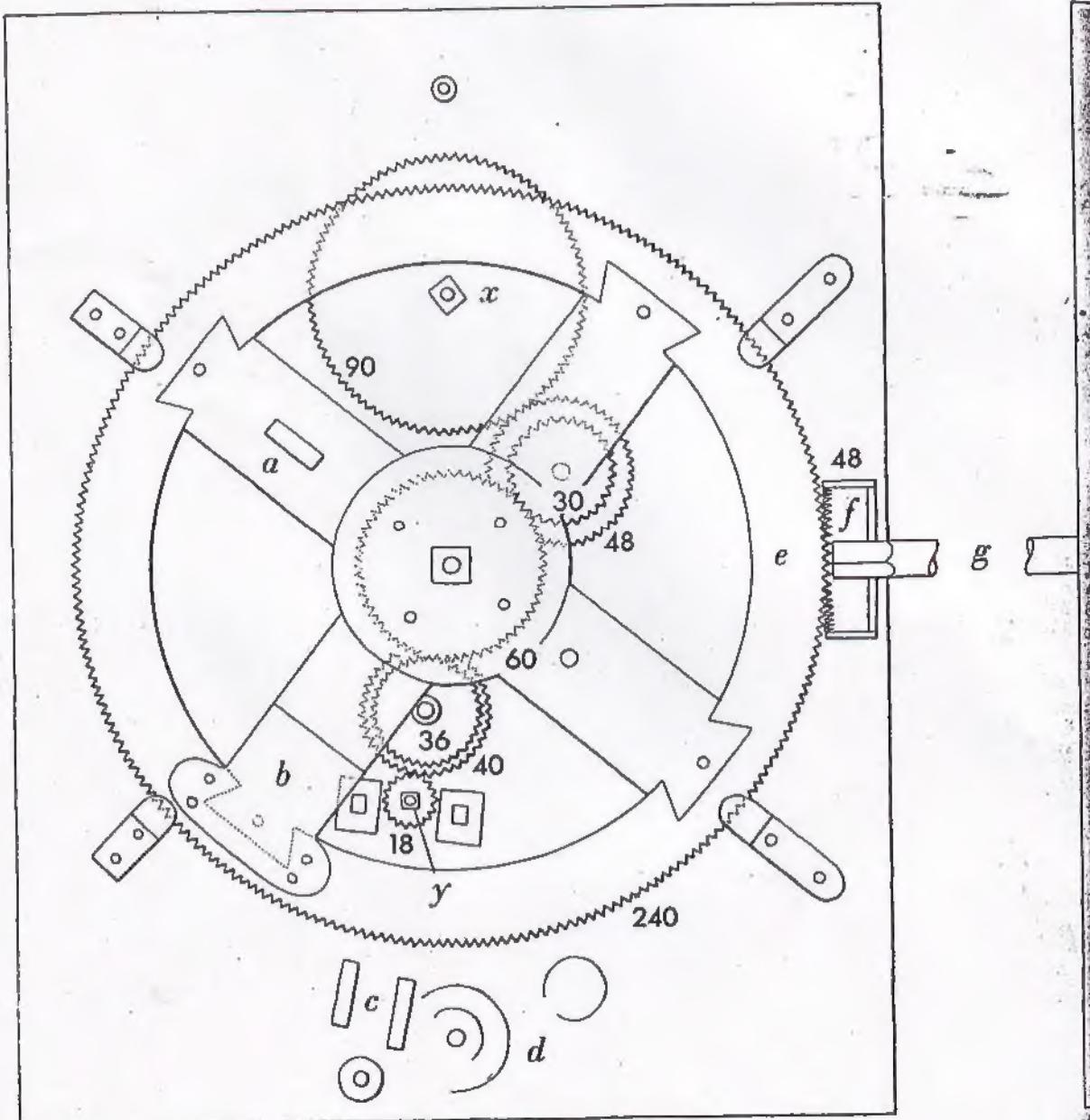
Putting together the information gathered so far, it seems reasonable to suppose that the whole purpose of the Antikythera device was to mechanize just this sort of cyclical relation, which was a strong feature of ancient astronomy. Using the cycles that have been mentioned, one could easily design gearing that would operate from one dial having a wheel that revolved annually, and turn by this gearing a series of other wheels which would move pointers indicating the sidereal, synodic and draconitic months. Similar cycles were known for the planetary phenomena; in fact, this type of arithmetical theory is the central theme of Seleucid Babylonian astronomy, which was transmitted to the Hellenistic world in the last few centuries B.C. Such arithmetical schemes are quite

distinct from the geometrical theory of circles and epicycles in astronomy, which seems to have been essentially Greek. The two types of theory were unified and brought to their peak in the second century A.D. by Claudius Ptolemy, whose labors marked the triumph of the new mathematical attitude toward geometrical models that still characterizes physics today.

The Antikythera mechanism must therefore be an arithmetical counterpart

of the much more familiar geometrical models of the solar system which were known to Plato and Archimedes and evolved into the orrery and the planetarium. The mechanism is like a great astronomical clock without an escapement, or like a modern analogue computer which uses mechanical parts to save tedious calculation. It is a pity that we have no way of knowing whether the device was turned automatically or by hand. It might have been held in the

hand and turned by a wheel at the side so that it would operate as a computer possibly for astrological use. I feel it is more likely that it was permanently mounted, perhaps set in a statue, and displayed as an exhibition piece. In that case it might well have been turned by the power from a water clock or some other device. Perhaps it is just such a wondrous device that was mounted inside the famous Tower of Winds in Athens. It is certainly very similar to the



0 1 2 3 4 5
CENTIMETERS

DETAILS OF THE MAIN MECHANISM are shown from the front (left) and the back (right). The numbers in the illustration refer to the approximate number of teeth on each gear. The parts labeled with letters are: lug to fix eccentric drum for the front dial (a); pair to spoke (b); guide channel for spring to hold gear of 18 teeth (c); rivets to

and astronomical cathedral clocks that were built all over Europe during the Renaissance.

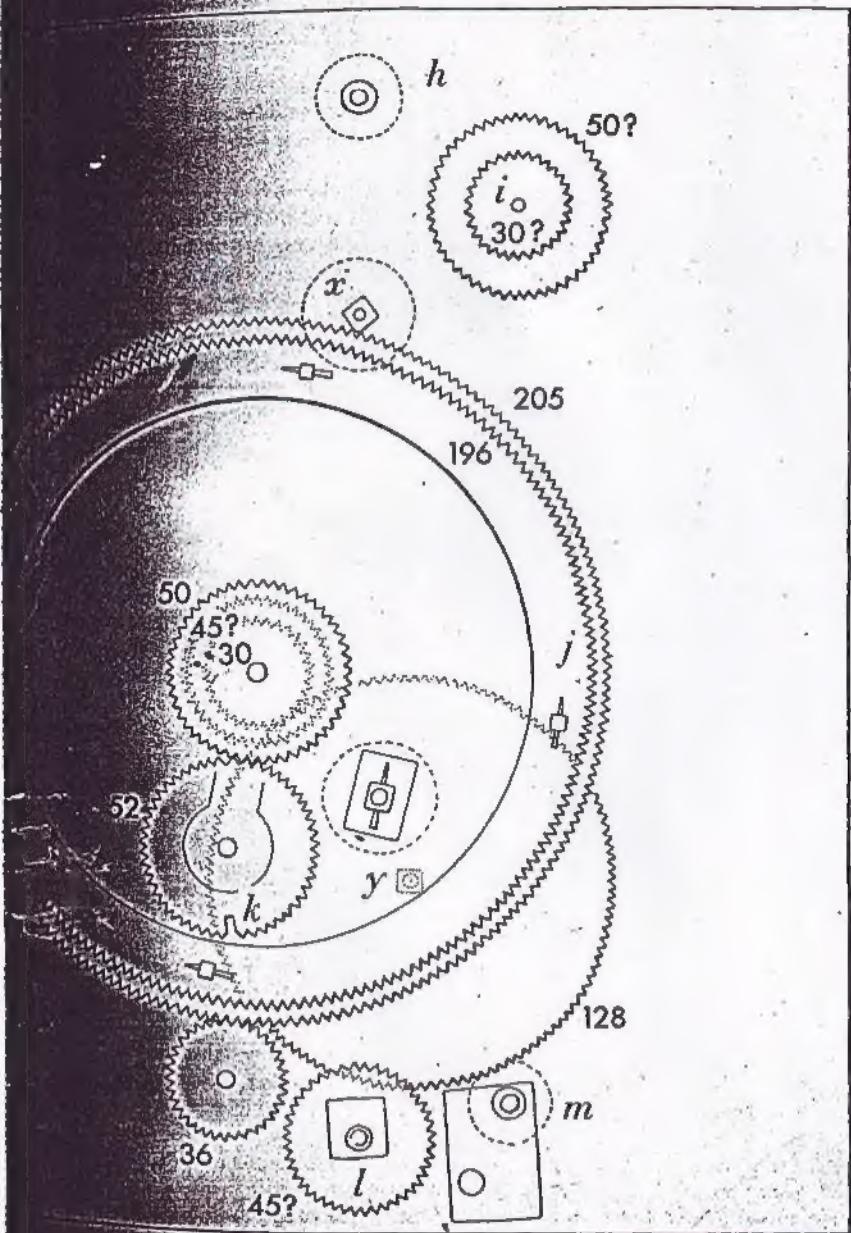
In the prehistory of the mechanical clock we must look for important analogies to the Antikythera mechanism and for an assessment of its significance. Unlike other mechanical devices, the clock did not evolve from the simple to the complex. The oldest clocks of which we are well informed were the most

complicated. All the evidence points to the fact that the clock started as an astronomical showpiece that happened also to indicate the time. Gradually the timekeeping functions became more important and the device that showed the marvelous clockwork of the heavens became subsidiary. Behind the astronomical clocks of the 14th century there stretches an unbroken sequence of mechanical models of astronomical theory. At the head of this sequence is the

Antikythera mechanism. Following it are instruments and clocklike computers known from Islam, from China and India and from the European Middle Ages. The importance of this line is very great, because it was the tradition of clock-making that preserved most of man's skill in scientific fine mechanics. During the Renaissance the scientific instrument-makers evolved from the clock-makers. Thus the Antikythera mechanism is, in a way, the venerable progenitor of all our present plethora of scientific hardware.

A significant passage in this story has to do with the astronomical computers of Islam. Preserved complete at the Museum of History of Science at Oxford is a 13th-century Islamic geared calendar-computer that has various periods built into it, so that it shows on dials the various cycles of the sun and moon. This design can be traced back, with slightly different periods but a similar arrangement of gears, to a manuscript written by the astronomer al-Biruni about 1000 A.D. Such instruments are much simpler than the Antikythera mechanism, but they show so many points of agreement in technical detail that it seems clear they come from a common tradition. The same 60-degree gear teeth are used; wheels are mounted on square-shanked axles; the geometrical layout of the gear assembly appears comparable. It was just at this time that Islam was drawing on Greek knowledge and rediscovering ancient Greek texts. It seems likely that the Antikythera tradition was part of a large corpus of knowledge that has since been lost to us but was known to the Arabs. It was developed and transmitted by them to medieval Europe, where it became the foundation for the whole range of subsequent invention in the field of clockwork.

On the one hand the Islamic devices knit the whole story together, and demonstrate that it is through ancestry and not mere coincidence that the Antikythera mechanism resembles a modern clock. On the other hand they show that the Antikythera mechanism was no flash in the pan but was a part of an important current in Hellenistic civilization. History has contrived to keep that current dark to us, and only the accidental underwater preservation of fragments that would otherwise have crumbled to dust has now brought it to light. It is a bit frightening to know that just before the fall of their great civilization the ancient Greeks had come so close to our age, not only in their thought, but also in their scientific technology.



The axles and support blocks at the back (*d*), main driving wheel (*e*), crown wheel (*f*), input axle (*g*), shaft of the upper-dial main pointer (*h*), shaft of the upper-dial subsidiary pointer (*i*), epicyclic turntable (*j*), repair to tooth (*k*), shaft of the lower-dial main pointer (*l*), shaft of the lower-dial subsidiary pointer (*m*), axles through the plate (*x* and *y*).